Design of CO_2 -Plume Geothermal (CPG) Subsurface System for Various Geologic Parameters

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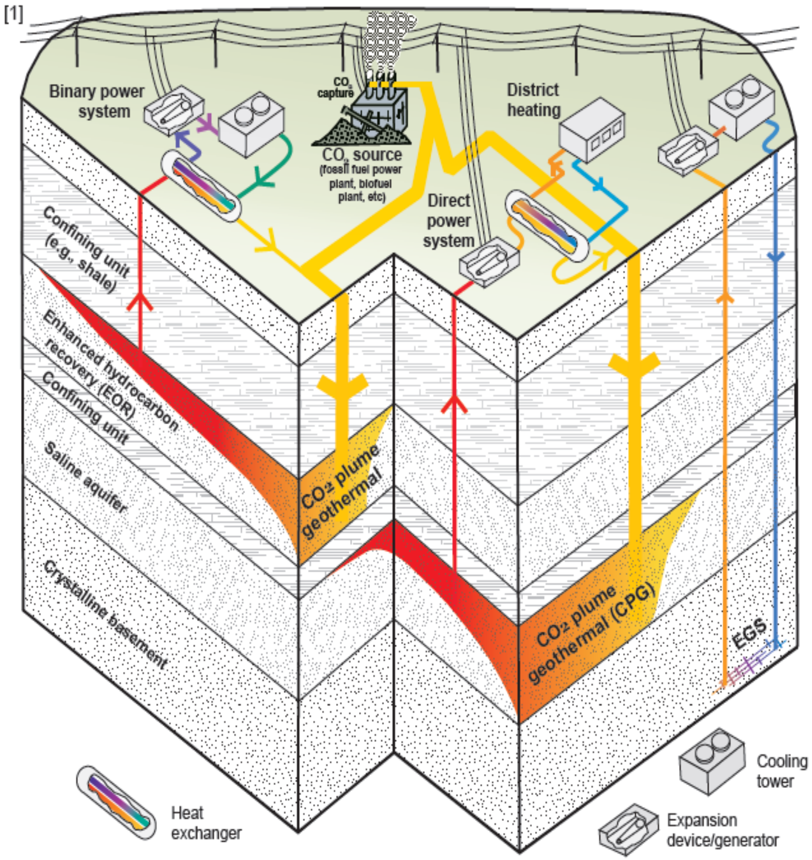
[1]



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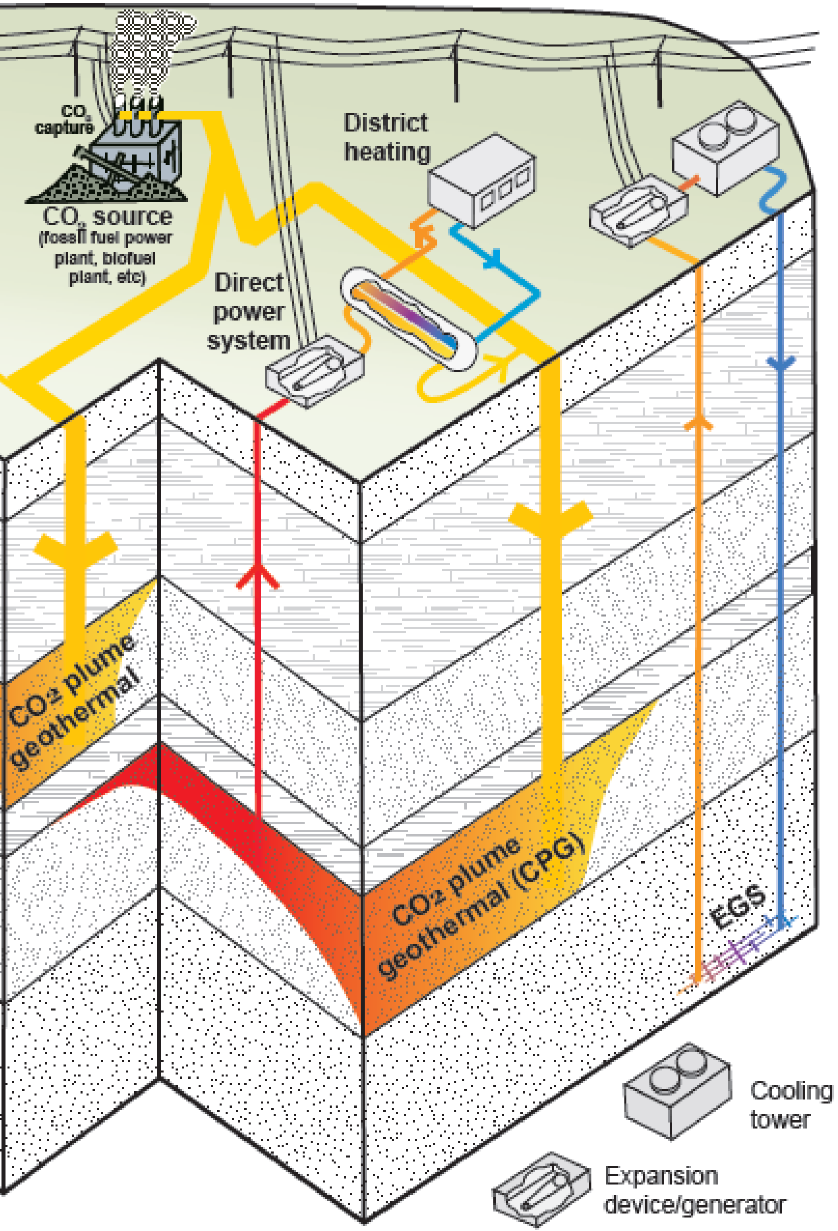
Background



EGS with CO_2

Brown, 2000, 2003, Fouillac et al., 2004, Pruess, 2006, 2007, 2008, Atrens et al., 2009

Advantages versus H_2O:
- higher efficiency

Problems:
- small reservoir
- induced seismicity
- maintaining permeability

CO_2 Plume Geothermal (CPG)

Randolph & Saar, GRL 2011.
U.S. Patent, November 2012.

Advantages:
- Larger reservoir
- High permeability
- CO_2 sequestration

Problems:
- All CCS challenges

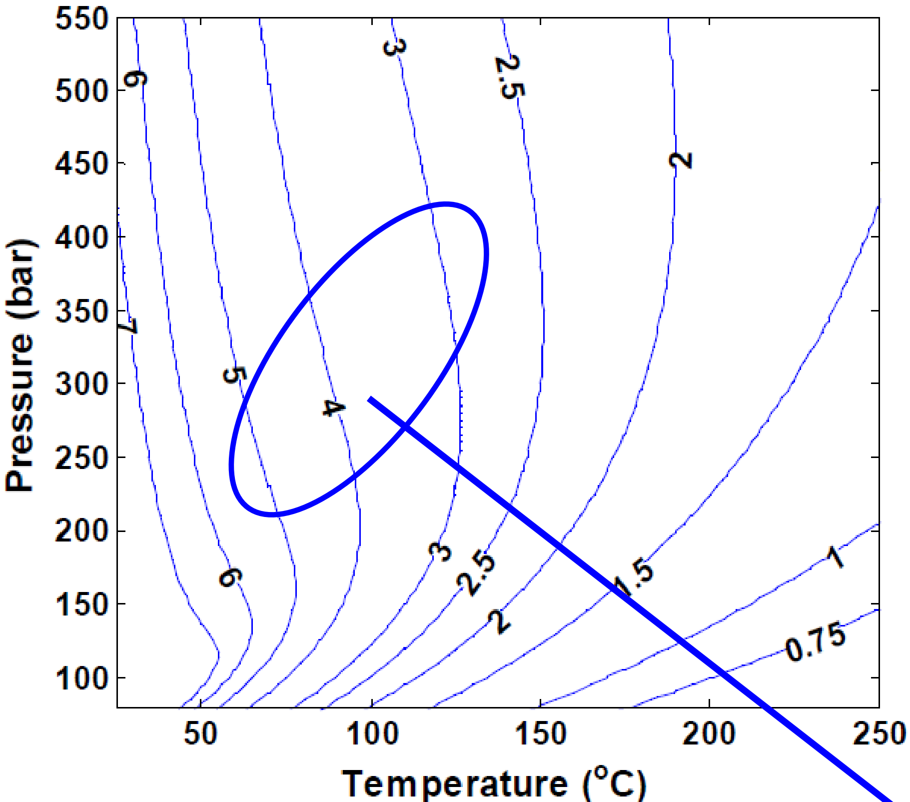
Why CO_2 as a geothermal working fluid ?

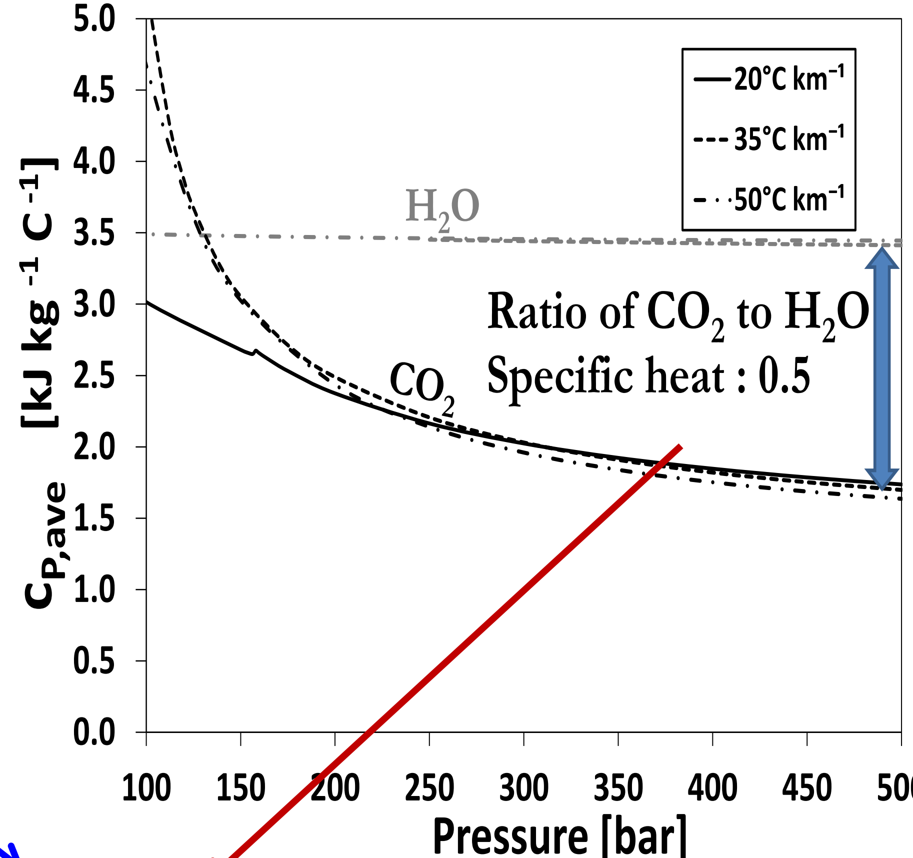
- Availability, disposable commodity (i.e., need to sequester CO_2 anyway, preserves water resources)
- Negative CO_2 emissions
- Offset part of the cost of and provide power for geologic CO_2 sequestration
- Provide a base load renewable electricity source
- Geothermal power plant benefits:
  - Greater-than-atmospheric operating pressure
  - Smaller equipment than conventional water-based facilities, hence smaller footprint
  - Capable of operating at below H_2O-freezing temperatures
- **Low temperature and less permeable formation are viable.**

Why CO_2 as a geothermal working fluid ?

$$C_{p,ave} = \frac{(h_{out,reservoir} - h_{in,reservoir})}{(T_{out,reservoir} - T_{in,reservoir})}$$

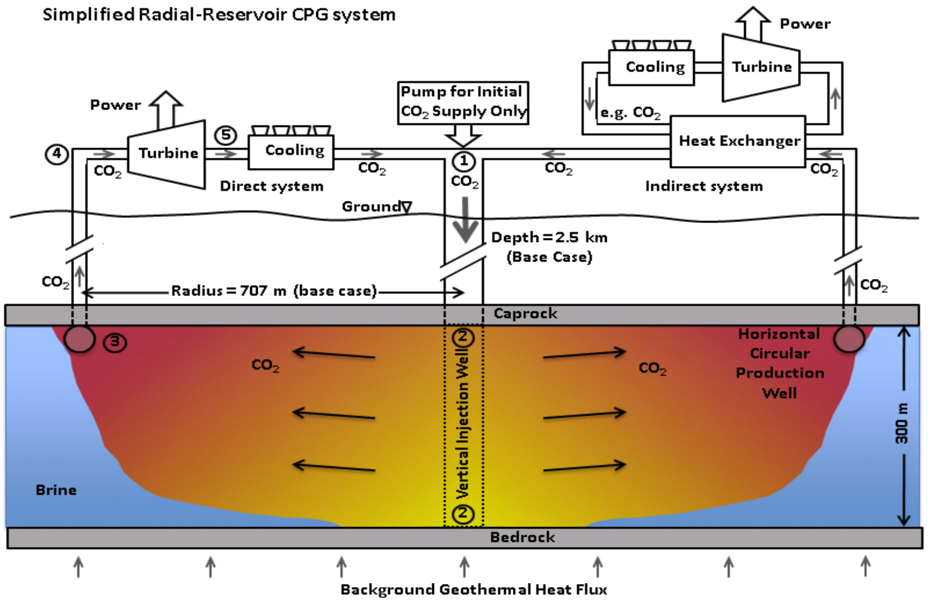
Ratio of CO_2 to H_2O Mobility $\left[\frac{\rho}{\mu}\right]$

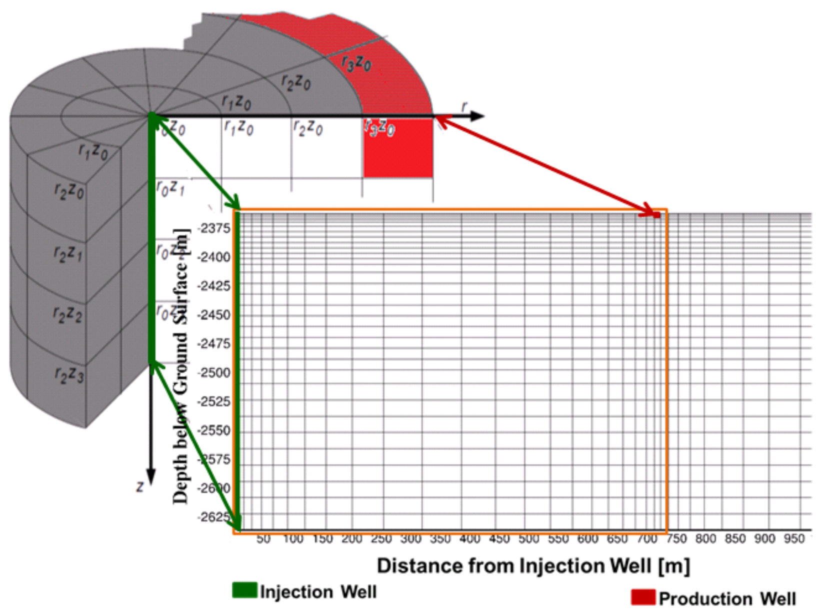




$$Q = \Delta P \left(\frac{kA}{L}\right) \boxed{\left[\frac{\rho}{\mu}\right]} \boxed{C_{p,ave}} \Delta T$$

Numerical Model





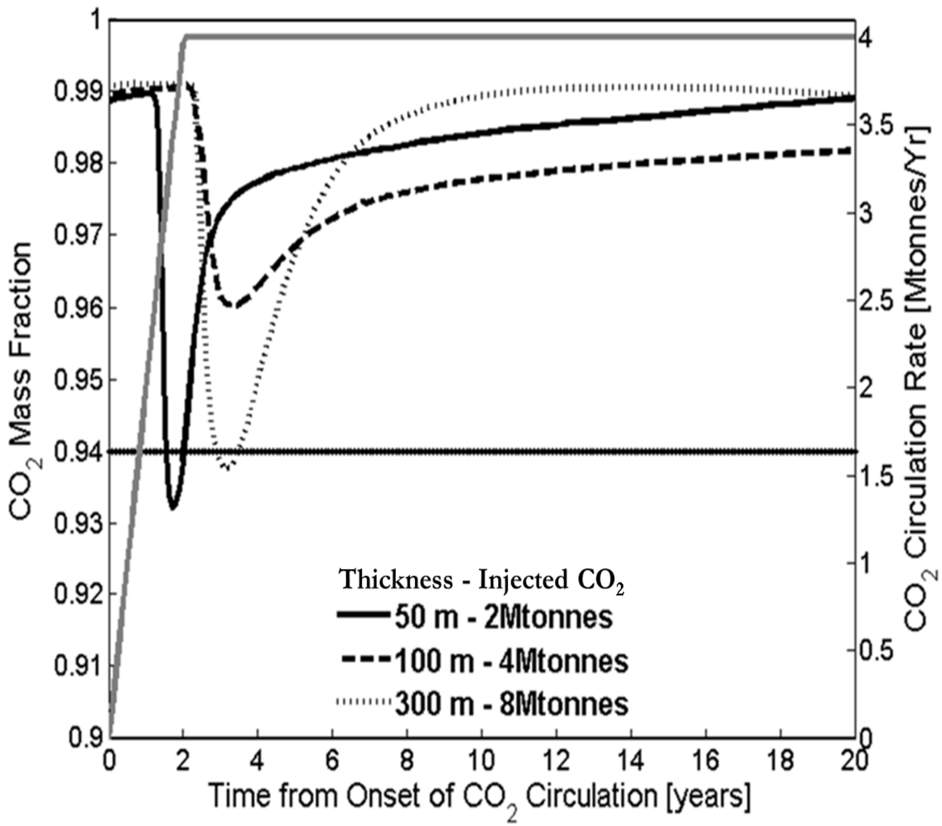
Reservoir Parameter/Condition	Value
Thickness [m]	300
Average depth, D [m]	2500
Porosity	0.10
Horizontal permeability, k_x [m^2]	5×10^{-14}
Vertical permeability, k_z [m^2]	2.5×10^{-14}
Geothermal gradient[^{0}C/km]	35
Temperature, T [^{0}C]	102.5
Thermal conductivity [W/m/^{0}C]	2.10
Rock specific heat [J/kg/^{0}C]	1000
Rock grain density [kg/m^3]	2650
Radius [m]	100,000

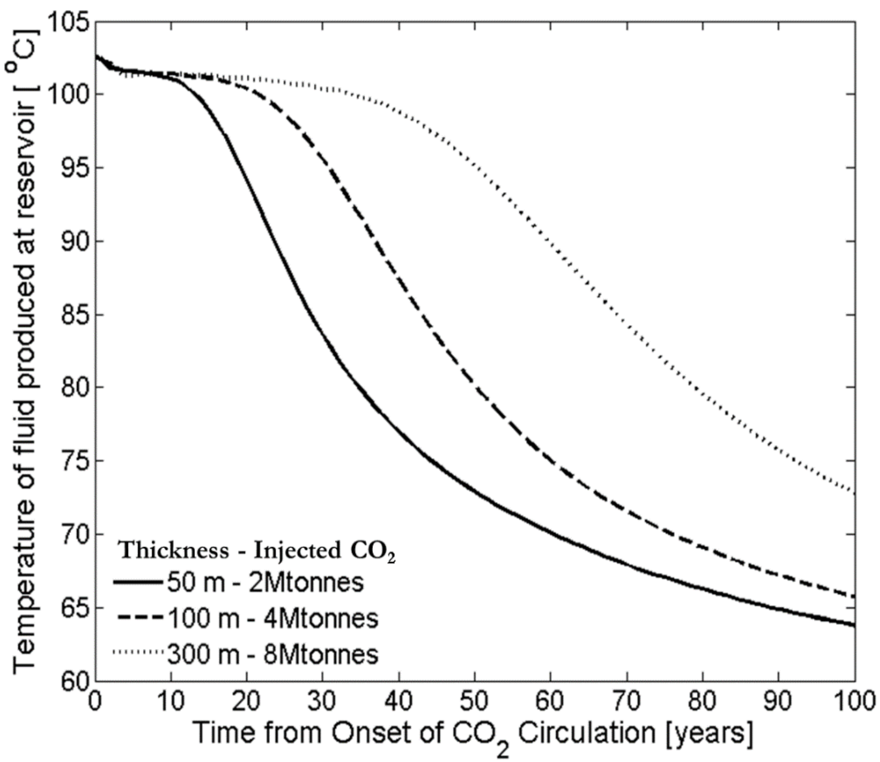
Boundary condition	Value
Top/bottom	No fluid flow, semi-analytic heat exchange
Lateral	No fluid or heat flow
Temperature of Injected fluid [^{0}C]	46

Reservoir Thickness

Thickness of Reservoir:

- Amount of CO_2 required ↑ with reservoir thickness for production of **CO_2-rich fluid (>94%)**[1] **.**
- The reservoir depletion rate ↓ with increase in reservoir thickness.





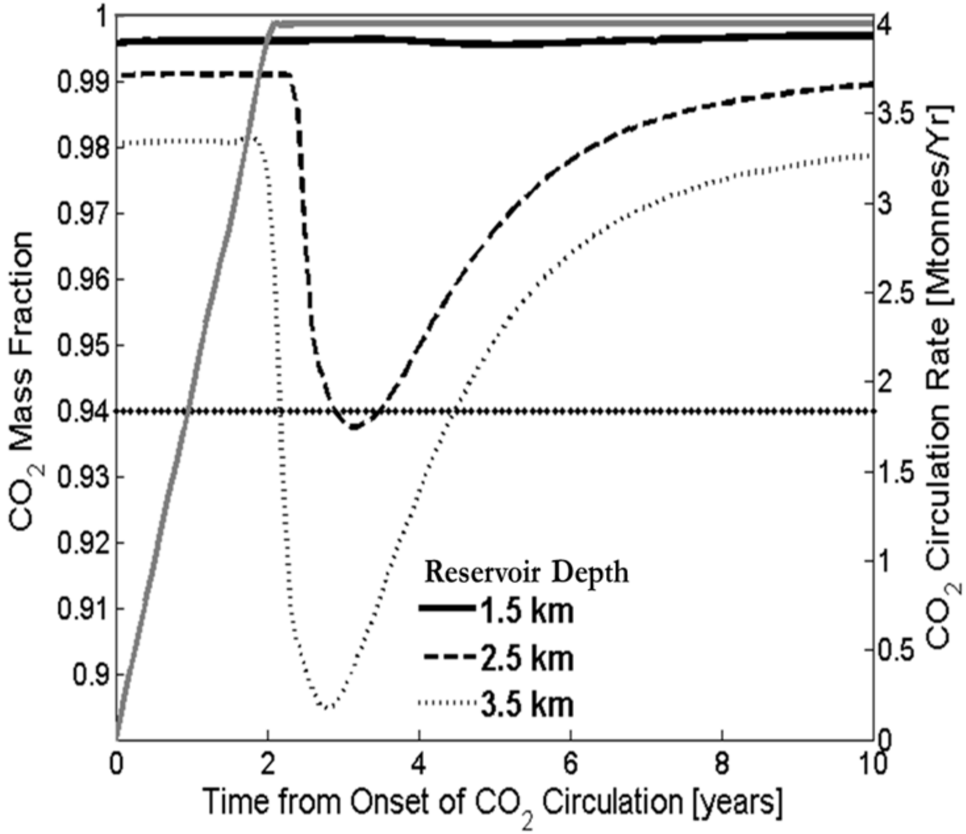
1. Welch, P., and P. Boyle, 2009, Geothermal Resources Council Transactions

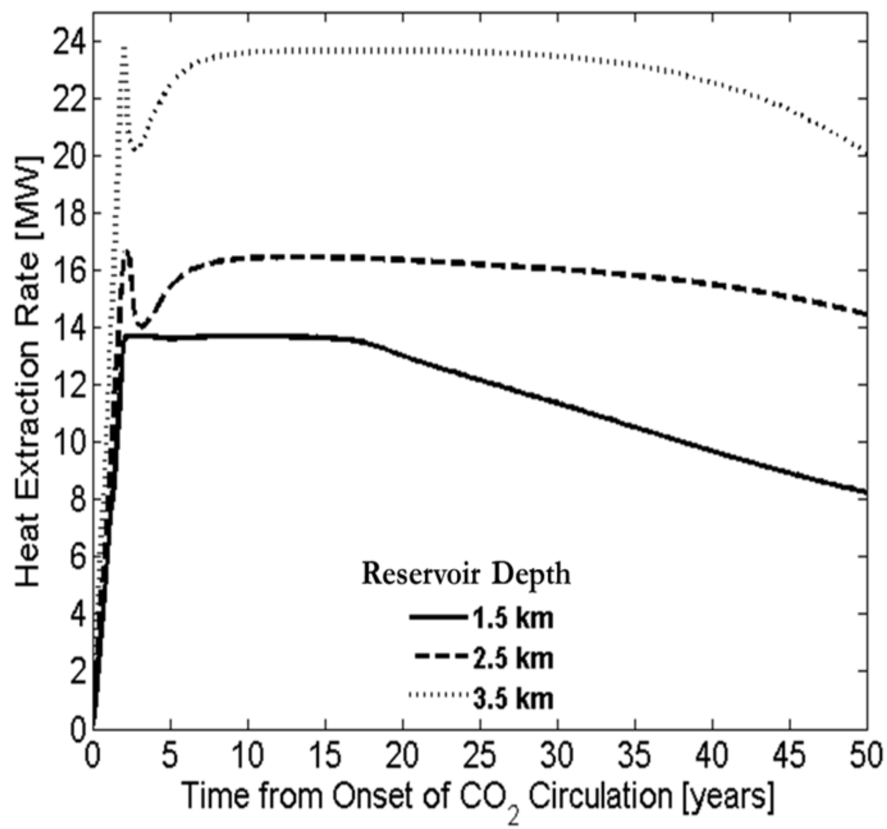
Reservoir Depth (T & P)

Depth (Geothermal Gradient: 35 $^0C/km$)

- As depth ↑ the amount of brine upconing into the produced fluid ↑.
- As depth ↑ the amount of heat extracted from the reservoir ↑ and at shallow depth depletion is fast.

Average depth, D [km]	Reservoir Pressure [bar]	Reservoir Temperature T [^0C]	Injection Temperature Tinj [^0C]
1.5	150	67.5	35
2.5	250	102.5	46
3.5	350	137.5	58

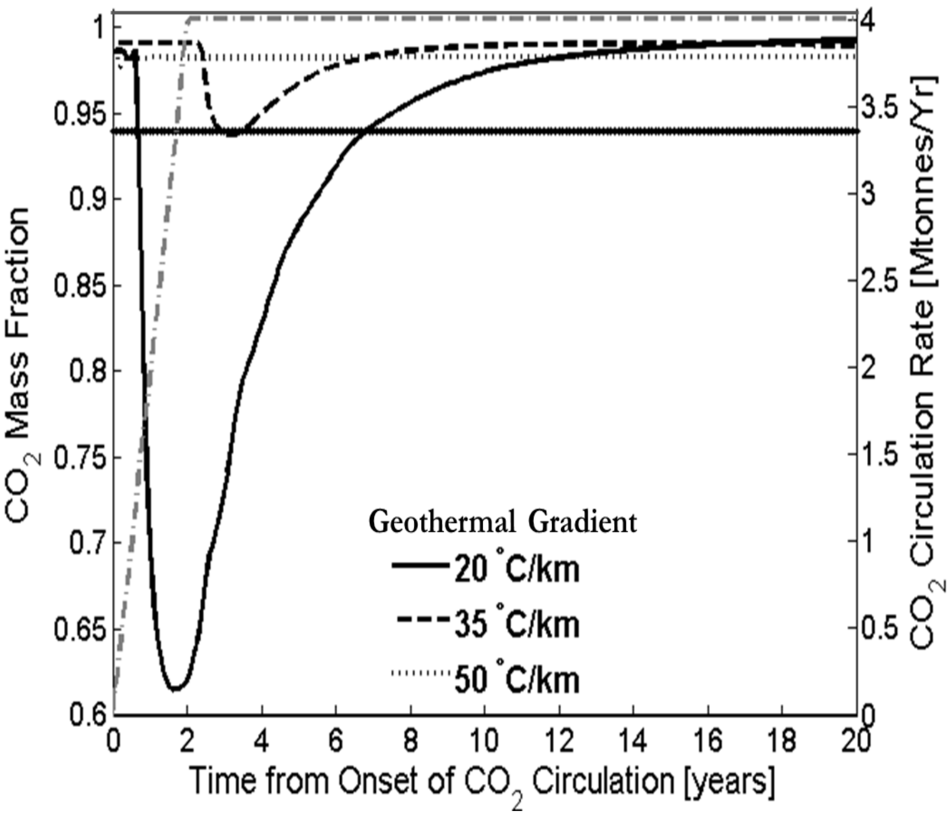


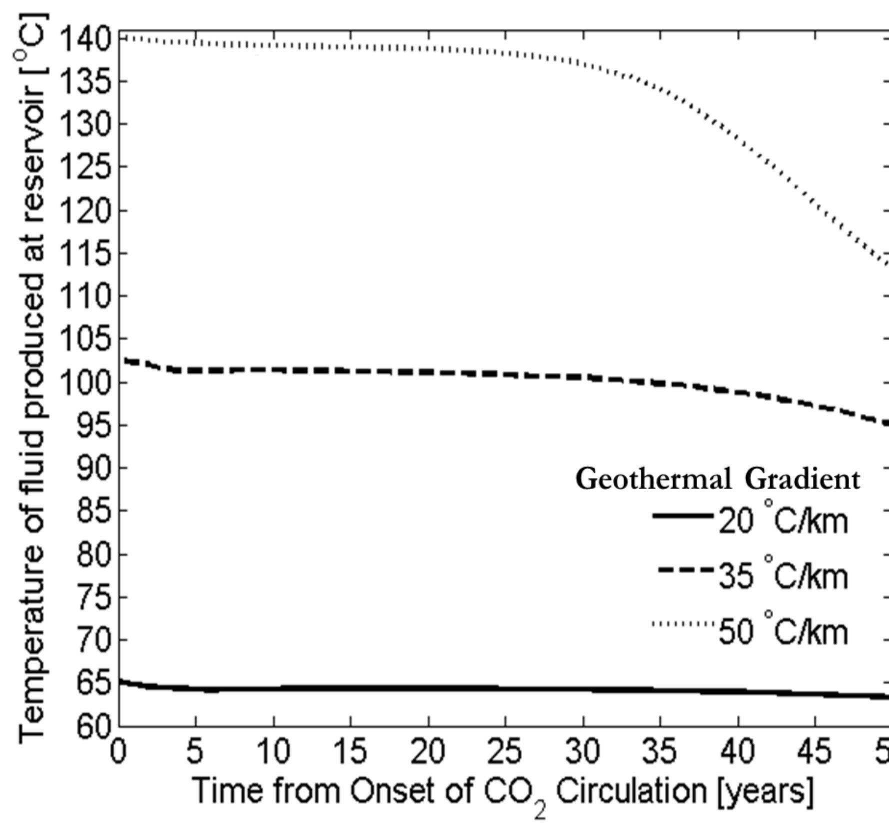


Geothermal Gradient (T)

Geothermal Gradient (Depth: 2.5 km)

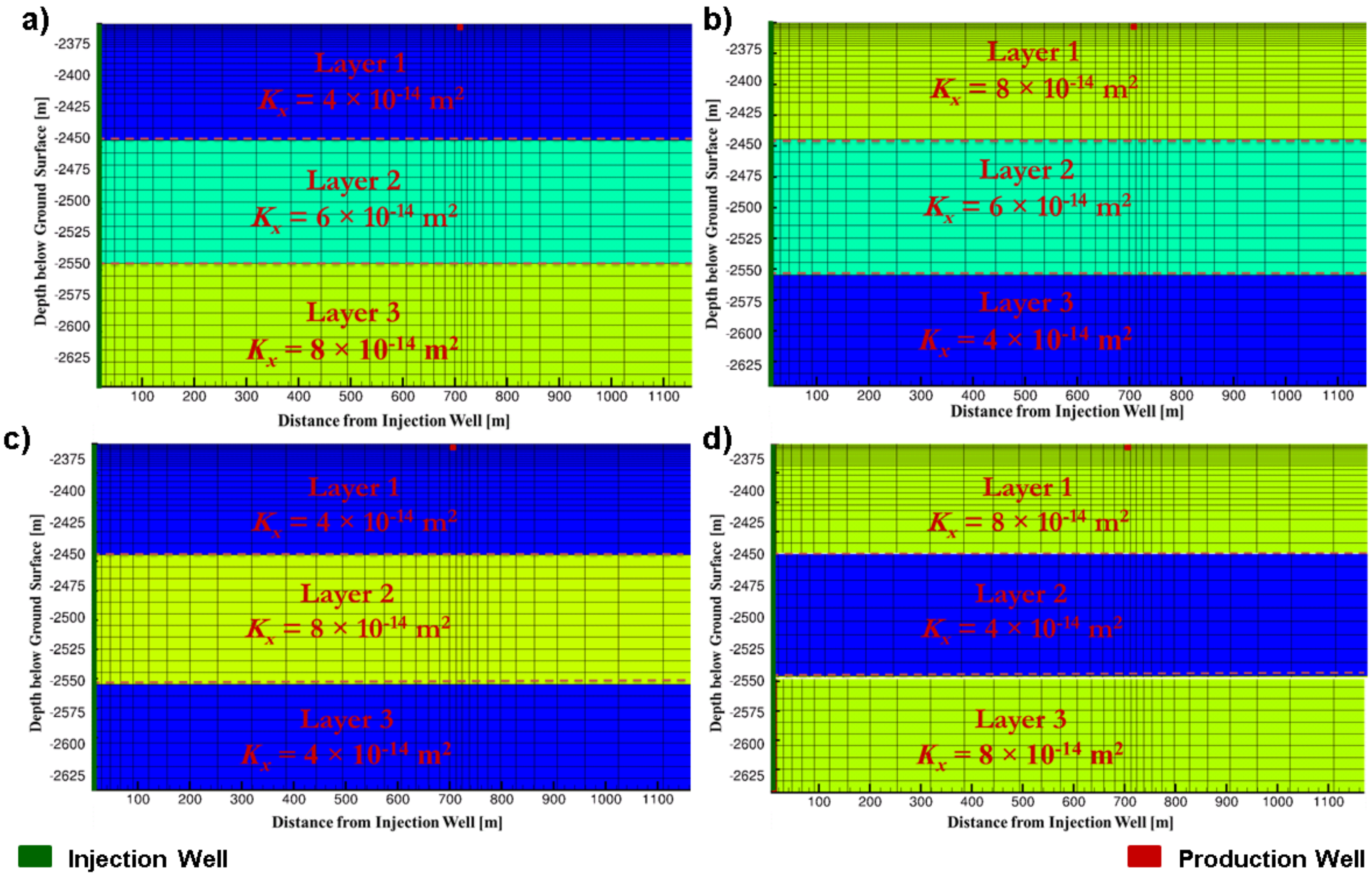
- Amount of CO_2 required is ↑ for locations with ↓ geothermal gradients.
- CO_2 plume saturation near the production well ↑ with geothermal gradient.
- The temperature depletion is fast at higher geothermal gradients.





Multi-layered Geothermal Systems

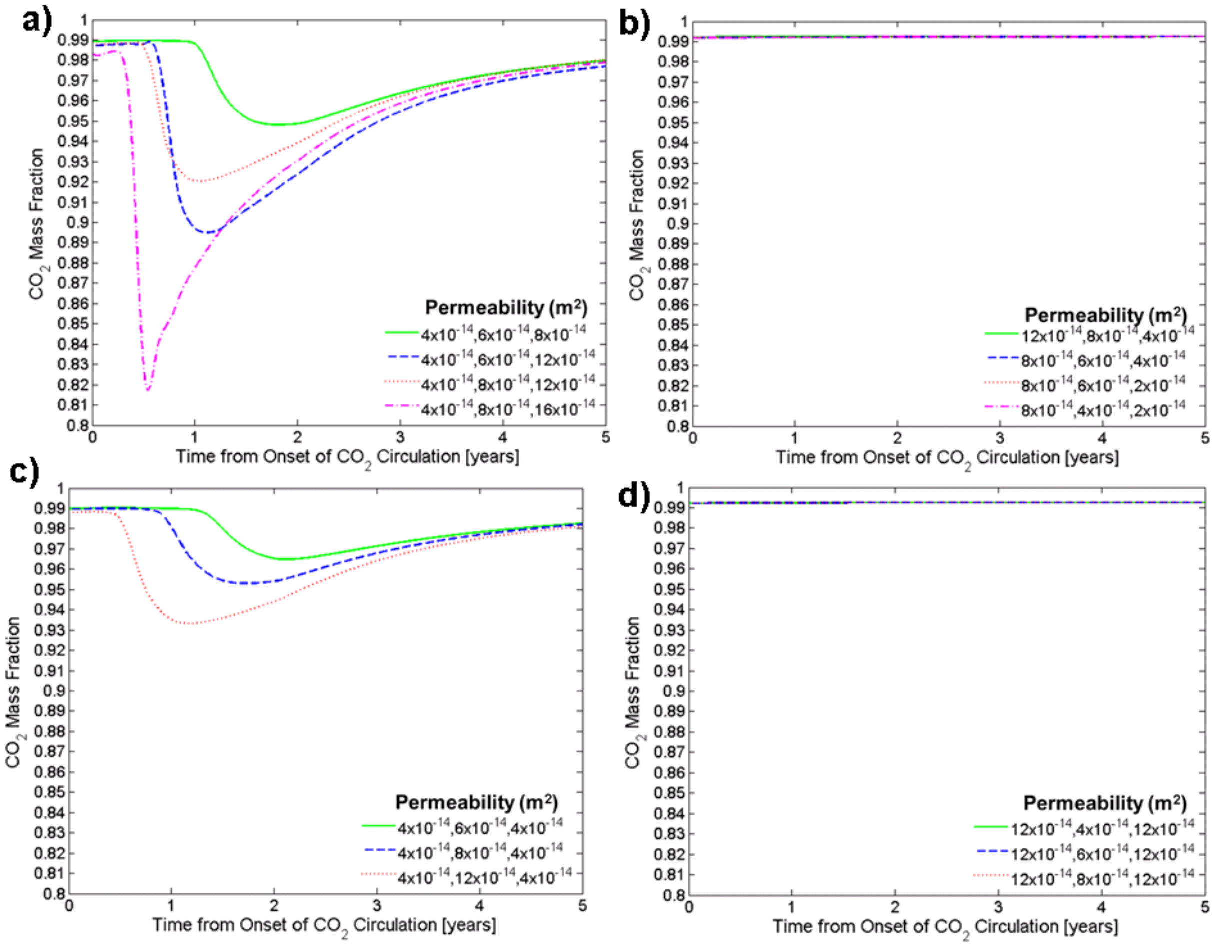
- In three- layered systems:
  - increasing permeability with depth
  - decreasing permeability with depth
  - alternate layers of high and low permeability layers
  - alternate layers of low and high permeability layers



Multi-Layer reservoir model with three layers

Multi-layered Geothermal Systems

- When the low-permeability layer is at the top, the CO_2 in the produced fluid is affected by the permeability of the bottom layers.
- When the permeability of the top layer is high, the effect of the bottom layer permeability is limited.

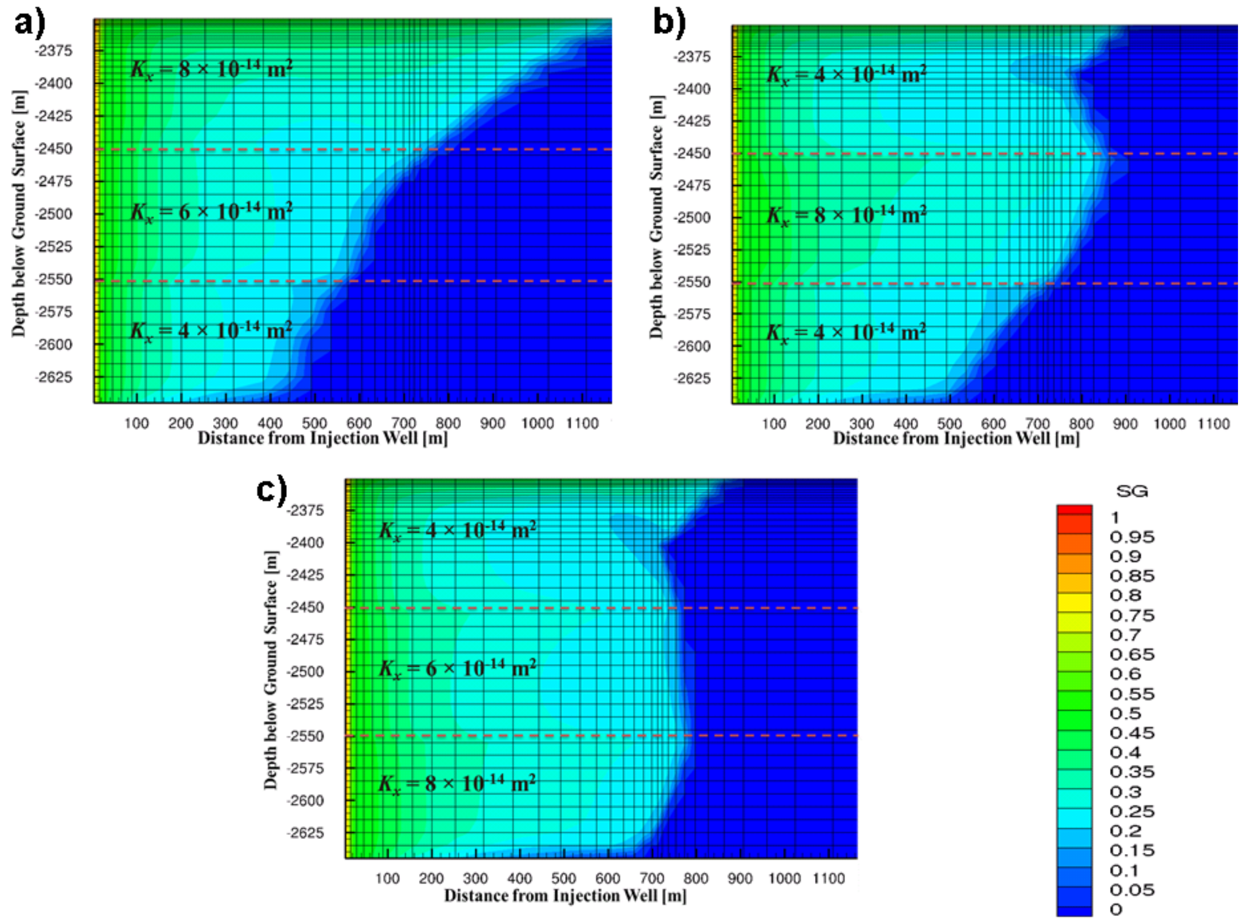


Multi-layered Geothermal Systems

Produced CO_2 mass fraction is dominated by the high-permeability layer and its stratigraphic position within the reservoir.

- The horizontal layers constitute a system of conductors arranged in parallel with respect to the main CO_2 flow direction.

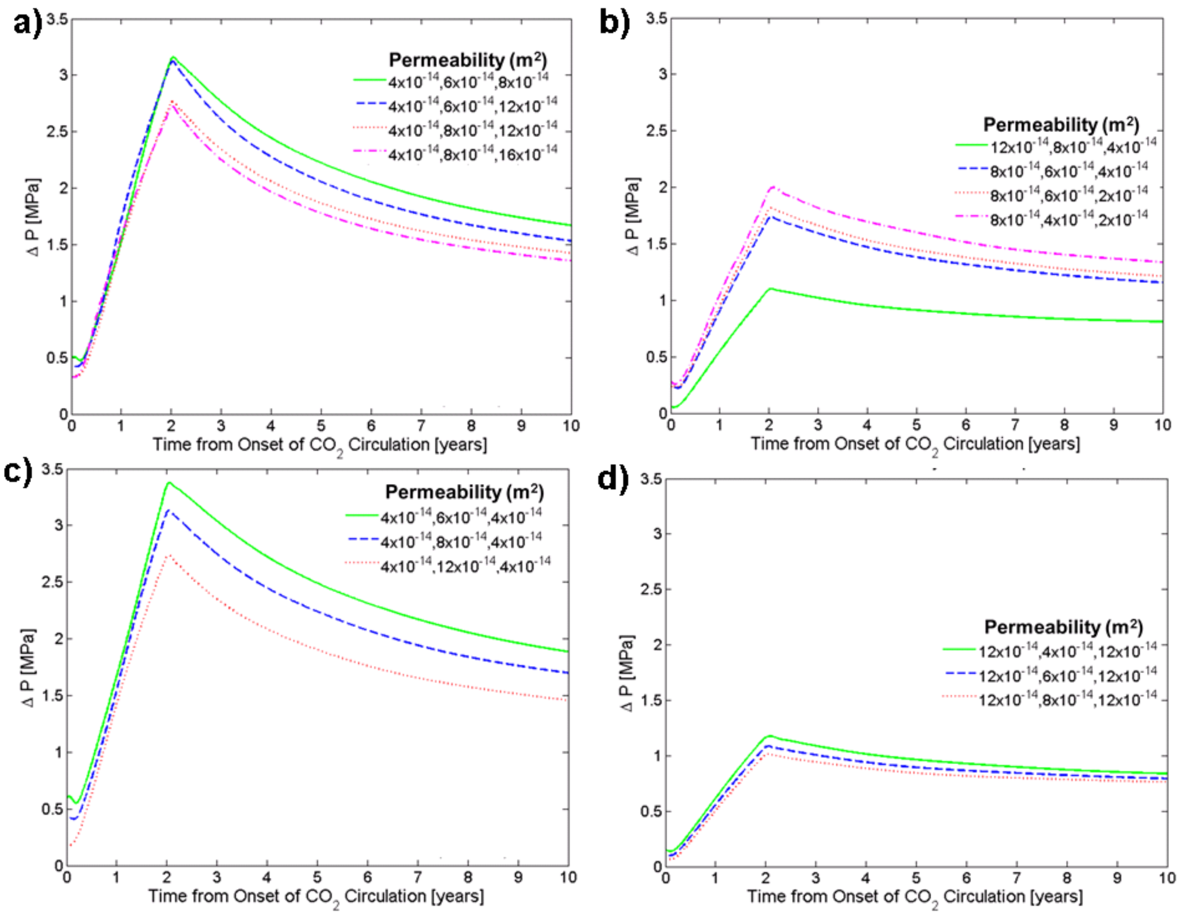
  Thus, the overall system permeability is dominated by the high-permeability layer.



Multi-layered Geothermal Systems

Pore-fluid pressure drop between the wells is affected by the permeability of all the layers in the reservoir.

- ➢ Pressure drop ↓ as the permeability of any layer ↑ either at the top or at the bottom.
- ➢ The pore-fluid pressure drop between the wells in a system with low-permeability layers at the top **>** high-permeability layers at the top.



Conclusions

Amount of CO_2 required (for CO_2>94% in production well):

- Amount of CO_2 required increases with reservoir thickness, and depth.
- Amount of CO_2 required decreases for higher geothermal gradients.

Reservoir Depletion:

- Reservoir depletion is slow for thick reservoirs.
- Reservoir depletes at a faster a rate at higher geothermal gradients, and shallow depths.

Multi-Layered Reservoir (Heterogeneous System):

- Produced CO_2 mass fraction is dominated by the high-permeability layer and their stratigraphic position within the reservoir.
- Pore-fluid pressure drop between the wells is affected by the permeability of all the layers in the reservoir.

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THANK YOU

Disclaimer

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http://energypathways.org/

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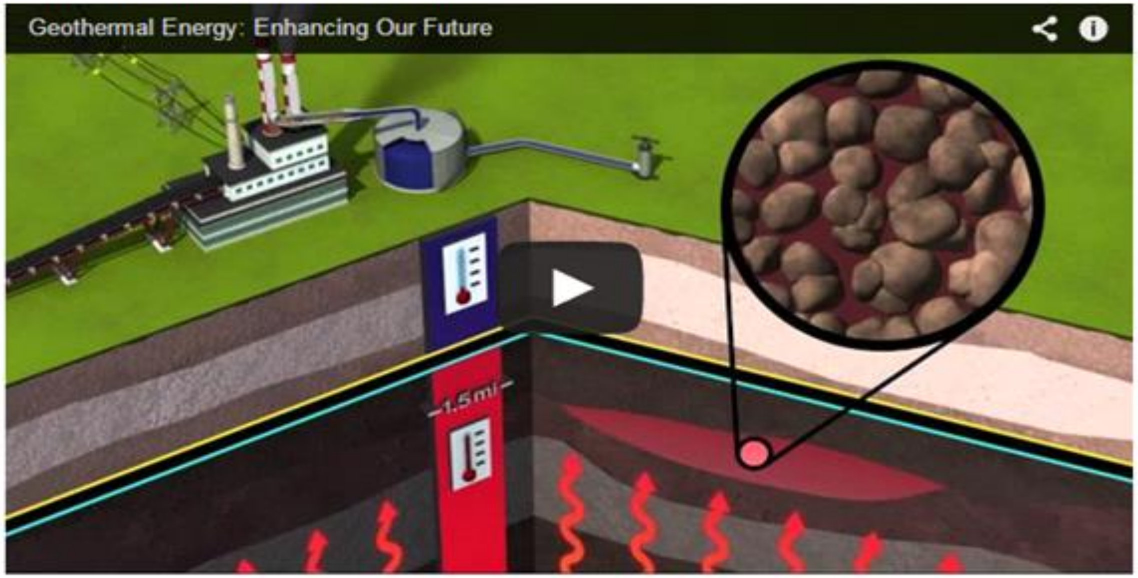
CO2 Geothermal



Video: Gilley, S., and Bielicki, J (2013). "Geothermal Energy: Enhancing Our Future." Online video. www.energypathways.org and YouTube. YouTube , 1 Dec. 2013. Web.

More information is available on the **Resources** tab of this website.

NEWS

Can We Turn Unwanted Carbon Dioxide Into Electricity?

New power plant design to expand use of geothermal energy in the U.S.

Researchers are developing a new kind of geothermal power plant that will lock away unwanted carbon dioxide (CO_2) underground—and use it as a tool to boost electric power generation by at least ten times compared to existing geothermal energy approaches. **Read More»**

Sustainable Energy Pathways (SEP) NSF-SEP-1230691

Conclusions

Amount of CO_2 required (for CO_2>94% in production well):

- Amount of CO_2 required increases with reservoir thickness, and depth.
- Amount of CO_2 required decreases for higher geothermal gradients.

Reservoir Depletion:

- Reservoir depletion is slow for thick reservoirs and moderate depths (2.5 km).
- Reservoir depletes at a faster a rate at higher geothermal gradients.

Multi-Layered Reservoir (Heterogeneous System):

- Produced CO_2 mass fraction is dominated by the high-permeability layer and their stratigraphic position within the reservoir.
- Pore-fluid pressure drop between the wells is affected by the permeability of all the layers in the reservoir.